Gustav Robert Kirchhoff, "Uber den Zusammenhang zwischen Emission und Absorption von Licht and Wärme," Monatsberichte der Akademie der Wissenschaften zu Berlin 1859 (December), pp. 783-787

Gustav Robert Kirchhoff, "On the Connection between Emission and Absorption of Light and Heat," Monthly Reports of the Academy of Sciences of Berlin 1859 (December), pp. 783-787

Mr. du Bois-Reymond submitted a message from Mr. Prof. Kirchhoff on the relationship between emission and absorption of light and heat, received Heidelberg, December 11, 1859.

A few weeks ago I had the privilege of communicating to the Academy some observations, which seemed to me of particular interest, because they allow conclusions about the chemical nature of the solar atmosphere. On the basis of these observations, I have now arrived at a general theorem by a very simple theoretical consideration, which seems to me to be of importance in many respects, and therefore allow me to submit it to the Academy. It expresses a property of all bodies, which refers to the emission and absorption of heat and light.

If sodium chloride or lithium chloride is brought into the non-luminous flame of Bunsen's lamp, a glowing body is obtained, which emits only light of a certain wavelength and absorbs only light of the same wavelength. In this way the result of the mentioned observations can be explained. How it behaves in relation to the dark rays of heat in relation to emission and absorption, we do not know; but it seems as unobjectionable to conceive of a body as possible, which emits only rays of one wavelength of all heat rays, the luminous and the dark, and absorbs only rays of the same wavelength. If one admits this and considers, moreover, a mirror which completely reflects all the rays than is possible, it can be easily proved from the general principles of mechanical heat theory that for rays of the same wavelength at the same temperature the ratio of the emissivity to the absorption capacity of all bodies is the same.

Imagine, in the form of an infinite plate, a body C which emits only rays of the wavelength Λ and absorbs only those rays; In opposition to this is a body c in the form of a similar plate emitting and absorbing rays of all possible wavelengths; the outer surfaces of these plates are covered with the perfect mirrors R and r. Once the equality of temperature in this system has been established, each of the two bodies must maintain the same temperature, that is to absorb by absorption as much heat as it loses by radiation. Now, of the rays that c emits, first consider those of a wavelength λ that is different from Λ. The body C has no influence on these rays; they are reflected by the mirror R as if C were not present, a certain part of them is then absorbed by c, the others reach the mirror R for the second time, are again reflected by it, partly absorbed by c, and so on. All beams of the wavelength λ that the body c emits become gradually so in this way taken up by it again. Since this holds for all values of λ which are different from Λ, the immutability of the temperature of the body c requires that it absorbs from the rays of the wavelength Λ as much as itself sending out. For this wavelength let e be the emissivity, a the absorption capacity of the body c, E and A are the corresponding magnitudes for the body C. From the set of rays E which are emitted by C, then c absorbs the set aE and reject $(1-a)E$; C of these absorbs the set $A(1-a)E$ and returns $(1-A)(1-a)E$ to c, of which $a(1-A)(1-a)E$ absorbed. Continuing with this consideration, we see that c receives a quantity of rays from E, which, if for brevity

$$(1-A)(1-a)=k$$

becomes

$$=aE(1+k+k^2+k^3+\cdots),$$

i. e.

$$=\frac{aE}{(1-k)}.$$

Of the quantity of rays e which c emits itself absorbs e, as a similar consideration shows, the quantity

$$\frac{a(1-A)e}{1-k}.$$

The condition that the temperature of c does not change is therefore the equation

$$e=\frac{aE}{1-k}+\frac{a(1-A)e}{1-k},$$

i. e. the equation

$$\frac{e}{a}=\frac{E}{A}.$$

The same equation can be reached by considering the condition designed so that the temperature of C remains constant. If one thinks of the body c as replaced by another at the same temperature, then by repeating the employed illumination, one finds the same value for the ratio of the emissivity to the absorption power of this body for the strands of the same wavelength Λ. The wavelength Λ and the temperature, however, are arbitrary. Hence, it follows that for rays of the same wavelength at the same temperature, the ratio of the emissivity to the absorbency is the same for all bodies.

The terms emissivity and absorbency refer initially to the case where the body forms an indefinite plate occupied on one side with a perfect mirror. But the quantity of rays which a free-standing plate sends forth to one side is just as great as the quantity of rays which a plate of half the thickness provided with such a mirror expands, and these two plates produce an equal absorption in incident rays. It can be said that the emissivity of the body is defined as the quantity of radiation emitted by a free-standing plate formed of the body to one side, and the capacity of absorption as the quantity of rays which absorbs the same plate from the whole of the amount of rays that hits them. The ratio of emissivity to absorbance $\frac{e}{a}$, which is common to all bodies, is a function of wavelength and temperature. At low temperatures, this function = 0 for the wavelengths of the visible rays, other than 0 for larger values of the wavelength; at higher temperatures the function has finite values for the wavelengths of the visible rays. At the temperature at which the function stops = 0 for the wavelength of a certain visible ray, all bodies begin to emit light of the colour of this ray, except those which have a vanishingly small absorption capacity for that colour and temperature; the greater the absorbency, the more light the body radiates out. The experience that the opaque bodies behave at the same temperature, but the transparent gases require a much higher temperature for this, and that the latter at the same temperature shine ever weaker than that, finds its explanation here. Further, when a glowing gas gives a discontinuous spectrum, and one walks through the same stratum of sufficient intensity, which in itself presents a spectrum without dark or light streaks, it follows that dark streaks must appear at the points of the spectra at which bright streaks in the spectrum of the glowing gas lay. The path which I have designated in my earlier communication as suitable for the chemical analysis of the solar atmosphere has hereby received its theoretical foundation. I use this opportunity to mention a success that I have gained in this way since my earlier participation. According to Wheatstone, Masson, Angström, and others, we know that in the spectrum of an electric spark, there are bright lines depending on the nature of the metals between which the spark jumps, and one can assume that these lines are in agreement with those that would form in the spectrum of a flame of very high temperature, if brought into this same metal in a suitable mode. I have examined the green part of the spectrum of the electric spark between iron electrodes, and have found in it a great number of bright lines, which seem to coincide with dark lines of the solar spectra. In the case of single lines the coincidence is scarcely to be established with certainty; but I have believed it to be seen in many groups in such a way that the brighter lines in the spark spectrum correspond to the darker ones in the sun spectrum; from this I believe to be

allowed to conclude that these coincidences were not only apparent but, as the spark was between other metals, e.g. formed between copper electrodes, these bright lines were missing. I consider myself justified in concluding that among the constituents of the glowing solar atmosphere is iron, a conclusion which, by the way, is very close, considering the frequent occurrence of iron in the earth and in the meteorites. From the dark lines of the solar spectrum, which seem to coincide with bright ones of the iron spectrum, I can only describe a few with reference to the drawing of the solar spectrum given by Fraunhofer; these include the line *E*, some less sharp lines close to *E* after the violet end of the spectrum, and a line between the two nearest of the three very excellent lines drawn by Fraunhofer at *b*.